VISIT…

3

Lubricating Oils

I. ADDITIVES

The preceding chapter discussed refining processes and base stock manufacturing. The lube oil base stock is the building block with respect to which appropriate additives are selected and properly blended to achieve a delicate balance in performance characteristics of the finished lubricant. It is important to mention again that the various base stock manufacturing processes can all produce base stocks with the necessary characteristics to formulate finished lubricants with the desirable performance levels. The key to achieving the highest levels of performance in finished lubricants is in the understanding of the interactions of base stocks and additives and matching those to requirements of machinery and operating conditions to which they can be subjected.

Additives are chemical compounds added to lubricating oils to impart specific properties to the finished oils. Some additives impart new and useful properties to the lubricant, some enhance properties already present, while some act to reduce the rate at which undesirable changes take place in the product during its service life.

Additives, in improving the performance characteristics of lubricating oils, have aided significantly in the development of improved prime movers and industrial machinery. Modern passenger car engines, automatic transmissions, hypoid gears, railroad and marine diesel engines, high speed gas and steam turbines, and industrial processing machinery, as well as many other types of equipment, would have been greatly retarded in their development were it not for additives and the performance benefits they provide.

Additives for lubricating oils were used first during the 1920s, and their use has since increased tremendously. Today, practically all types of lubricating oil contain at least one additive, and some oils contain additives of several different types. The amount of additive used varies from a few hundredths of a percent to 30% or more.

In addition to their beneficial effects, additives can have detrimental side effects, especially if the dosage is excessive or if interactions with other additives occur. It is the responsibility of the oil formulator to achieve a balance of additives for optimum performance, and to ensure by testing that this combination is not accompanied by undesirable

Copyright 2001 by Exxon Mobil Corporation. All Rights Reserved.

side effects. When this is achieved, it is usually unnecessary and undesirable for the oil user to add oil additive supplements.

The more commonly used additives are discussed in the following sections. Although some are multifunctional, as in the case of certain VI improvers that also function as pour point depressants or dispersants or antiwear agents that also function as oxidation inhibitors, they are discussed in terms of their primary function only.

A. Pour Point Depressants

Certain high molecular weight polymers function by inhibiting the formation of a wax crystal structure that would prevent oil flow at low temperatures. Two general types of pour point depressant are used:

1. Alkylaromatic polymers adsorb on the wax crystals as they form, preventing them from growing and adhering to each other.
2. Polymethacrylates cocrystallize with wax to prevent crystal growth.

The additives do not entirely prevent wax crystal growth, but rather lower the temperature at which a rigid structure is formed. Depending on the type of oil, pour point depression of up to 50°F (28°C) can be achieved by these additives, although a lowering of the pour point by about 20–30 F° (11–17 C°) is more common.

B. Viscosity Index Improvers

VI improvers are long chain, high molecular weight polymers that function by causing the relative viscosity of an oil to increase more at high temperatures than at low temperatures. Generally this result is due to a change in the polymer's physical configuration with increasing temperature of the mixture. It is postulated that in cold oil the molecules of the polymer adopt a coiled form so that their effect on viscosity is minimized. In hot oil, the molecules tend to straighten out, and the interaction between these long molecules and the oil produces a proportionally greater thickening effect. *Note:* Although the oil–polymer mixture still decreases in viscosity as the temperature increases, the decrease is not as great as it would have been in the oil alone.

Among the principal VI improvers are methacrylate polymers and copolymers, acrylate polymers, olefin polymers and copolymers, and styrene butadiene copolymers. The degree of VI improvement from these materials is a function of the molecular weight distribution of the polymer.

The long molecules in VI improvers are subject to degradation due to mechanical shearing in service. Shear breakdown occurs by two mechanisms. Temporary shear breakdown occurs under certain conditions of moderate shear stress and results in a temporary loss of viscosity. Apparently, under these conditions the long molecules of the VI improver align themselves in the direction of the stress, thus reducing resistance to flow. When the stress is removed, the molecules return to their usual random arrangement and the temporary viscosity loss is recovered. This effect can be beneficial in that it can temporarily reduce oil friction to permit easier starting, as in the cranking of a cold engine. Permanent shear breakdown occurs when the shear stresses actually rupture the long molecules, converting them into lower molecular weight materials, which are less effective VI improvers. This results in a permanent viscosity loss, which can be significant. It is generally the limiting factor controlling the maximum amount of VI improver that can be used in a particular oil blend.

Copyright 2001 by Exxon Mobil Corporation. All Rights Reserved.

VI improvers are used in engine oils, automatic transmission fluids, multipurpose tractor fluids, and hydraulic fluids. They are also used in automotive gear lubricants. Their use permits the formulation of products that provide satisfactory lubrication over a much wider temperature range than is possible with straight mineral oils alone.

C. Defoamants

The ability of oils to resist foaming varies considerably depending on type of crude oil, type and degree of refining, and viscosity. In many applications, there may be considerable tendency to agitate the oil and cause foaming, while in other cases even small amounts of foam can be extremely troublesome. In these cases, a defoamant may be added to the oil.

Silicone polymers used at a few parts per million are the most widely used defoamants. These materials are essentially insoluble in oil, and the correct choice of polymer size and blending procedures is critical if settling during long-term storage is to be avoided. Also, these additives may increase air entrainment in the oil. Organic polymers are sometimes used to overcome these difficulties with the silicones, although much higher concentrations are generally required.

It is thought that the defoamant droplets attach themselves to the air bubbles and can either spread or form unstable bridges between bubbles, which then coalesce into larger bubbles, which in turn rise more readily to the surface of the foam layer where they collapse, thus releasing the air.

D. Oxidation Inhibitors

When oil is heated in the presence of air, oxidation occurs. As a result of this oxidation, both the oil viscosity and the concentration of organic acids in the oil increase, and varnish and lacquer deposits may form on hot metal surfaces exposed to the oil. In extreme cases, these deposits may be further oxidized to form hard, carbonaceous materials.

The rate at which oxidation proceeds is affected by several factors. As the temperature increases, the rate of oxidation increases exponentially. A rule of thumb is that for each 10°C (18°F) rise in temperature, the oxidation rate of mineral oil will double. Greater exposure to air (and the oxygen it contains), or more intimate mixing with it, will also increase the rate of oxidation. Many materials, such as metals, particularly copper and iron and organic and mineral acids, may act as catalysts or oxidation promoters.

Although the complete mechanism of oil oxidation is not too well defined, it is generally recognized as proceeding by free radical chain reaction. Reaction chain initiators are formed first from unstable oil molecules, and these react with oxygen to form peroxy radicals, which in turn attack the unoxidized oil to form new initiators and hydroperoxides. The hydroperoxides are unstable and divide, forming new initiators to expand the reaction. Any materials that will interrupt this chain reaction will inhibit oxidation. Two general types of oxidation inhibitor are used: those that react with the initiators, peroxy radicals, and hydroperoxides to form inactive compounds, and those that decompose these materials to form less reactive compounds.

At temperatures below 200°F (93°C), oxidation proceeds slowly and inhibitors of the first type are effective. Examples of this type are hindered (alkylated) phenols such as 2,6-ditertiary-butyl-4-methylphenol (also called 2,6 ditertiary-butylparacresol, DBPC), and aromatic amines such as *N*-phenyl-α-naphthylamine. These are used in products such

Copyright 2001 by Exxon Mobil Corporation. All Rights Reserved.

as turbine, circulation, and hydraulic oils, which are intended for extended service at moderate temperatures.

When the operating temperature exceeds about 200°F (93°C), the catalytic effects of metals become important factors in promoting oil oxidation. Under these conditions, inhibitors that reduce the catalytic effect of the metals must be used. These materials usually react with the surfaces of the metals to form protective coatings and for that reason are sometimes called metal deactivators. Typical of additives of this type are the dithiophosphates, primarily zinc dithiophosphate. Since the dithiophosphates also act to decompose hydroperoxides at temperatures above 200°F (93°C), they inhibit oxidation by this mechanism as well.

Oxidation inhibitors may not entirely prevent oil oxidation when conditions of exposure are severe, and some types of oil are inhibited to a much greater degree than others. Oxidation inhibitors are not, therefore, cure-alls, and the formulation of a satisfactorily stable oil requires proper refining of a suitable base stock combined with careful selection of the type and concentration of oxidation inhibitor. It should also be pointed out that other additives can reduce oxidation stability in performing their design functions. Proper formulation requires the balancing of all the additive reactions to achieve the desired total performance characteristics.

E. Rust and Corrosion Inhibitors

A number of kinds of corrosion can occur in systems served by lubricating oils. Probably the two most important types are corrosion by organic acids that develop in the oil itself and corrosion by contaminants that are picked up and carried by the oil.

Corrosion by organic acids can occur, for example, in the bearing inserts used in internal combustion engines. Some of the metals used in these inserts, such as the lead in copper-lead or lead-bronze, are readily attacked by organic acids in oil, as illustrated in Figure 3.1. The corrosion inhibitors form a protective film on the bearing surfaces that

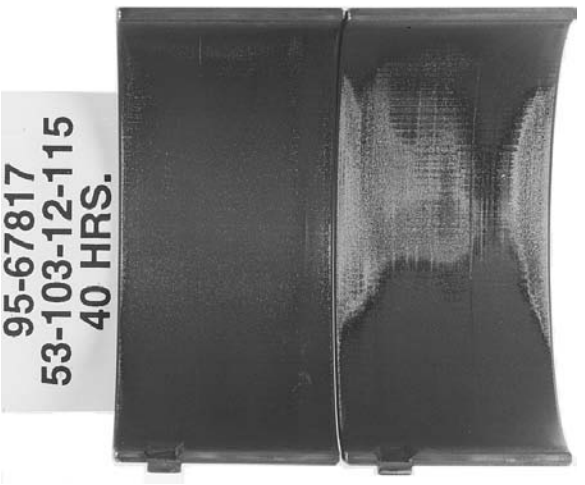

Figure 3.1 Heavily corroded copper-lead bearing.

Copyright 2001 by Exxon Mobil Corporation. All Rights Reserved.

Figure 3.2 Satisfactorily protected copper-lead bearing.

prevents the corrosive materials from reaching or attacking the metal (Figure 3.2). The film may be either adsorbed on the metal or chemically bonded to it.

During combustion in gasoline or diesel engines, certain materials in the fuel, such as sulfur and antiknock scavengers, can burn to form strong acids. These acids can then condense on the cylinder walls and be carried to other parts of the engine by the lubricant. Corrosive wear of rings and cylinder walls, and corrosion of crankshafts, rocker arms, and other engine components can then occur.

It has been found that the inclusion of highly alkaline materials in the oil will help to neutralize these strong acids as they are formed, greatly reducing this corrosion and corrosive wear. These alkaline materials are also used to provide detergency. See the detailed discussion in Section I.F, Detergents and Dispersants.

Rust inhibitors are usually compounds having a high polar attraction toward metal surfaces. By physical or chemical interaction at the metal surface, they form a tenacious, continuous film that prevents water from reaching the metal surface. Typical materials used for this purpose are amine succinates and alkaline earth sulfonates. The effectiveness of a properly selected rust inhibitor is illustrated in Figure 3.3, where specimen 9 is rust free and the other specimens display varying degree of corrosion.

Rust inhibitors can be used in most types of lubricating oil, but the selection must be made carefully to avoid problems such as corrosion of nonferrous metals or the formation of troublesome emulsions with water. Because rust inhibitors are adsorbed on metal surfaces, an oil can be depleted of rust inhibitor in time.

F. Detergents and Dispersants

In internal combustion engine service, a variety of effects tends to cause oil deterioration and the formation of harmful deposits. These deposits can interfere with oil circulation, build up behind piston rings to cause ring sticking and rapid ring wear, and affect clearances and proper functioning of critical components, such as hydraulic valve lifters. Once formed, such deposits are generally hard to remove except by mechanical cleaning. The use of

Copyright 2001 by Exxon Mobil Corporation. All Rights Reserved.

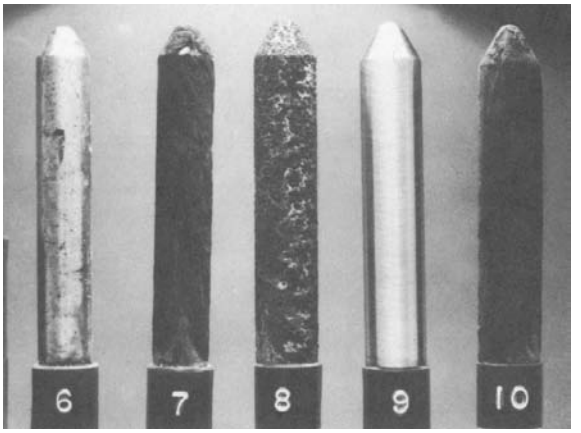

Figure 3.3 ASTM rust test specimens.

detergents and dispersants in the oil can delay the formation of deposits and reduce the rate at which they accumulate on metal surfaces. An essential factor with this approach is regular draining and replacement of the oil so that the contaminants in it are removed from the engine before the oil's capacity to hold them is exceeded.

Detergents are generally considered to be chemical compounds that chemically neutralize deposit precursors that form under high temperature conditions or as the result of burning fuels with high sulfur content or other materials that form acidic combustion by-products. Dispersants, on the other hand, are chemical compounds that disperse or suspend in the oil potential sludge- or varnish-forming materials, particularly those formed during low temperature operation when condensation and partially burned fuel find their way into the oil. These contaminants are removed from the system when the oil is drained. There is no sharp line of demarcation between detergents and dispersants. Detergents have some ability to disperse and suspend contaminants, while dispersants have some ability to prevent the formation of high temperature deposits.

The principal detergents used today are organic soaps and salts of alkaline earth metals such as barium, calcium, and magnesium. These materials are often referred to as metallo-organic compounds. Calcium and magnesium sulfonates, and calcium phenates (or phenol sulfides) are widely used. The sulfonates and phenates may be neutral or overbased; that is, they may contain more of the alkaline metal than is required to neutralize the acidic components used in diesel engine oils to neutralize the strong acids formed from combustion of the sulfur in the fuel. This neutralization reduces corrosion and corrosive wear and minimizes the tendency of these acids to cause oil degradation.

Overbased materials are generally used at lower concentration in gasoline engine oils, where the fuel sulfur is much lower. The overbased materials are included in the formulation to help reduce corrosion in low temperature operation. Both neutral and overbased materials also act to disperse and suspend potential varnish forming materials resulting from oil oxidation, preventing these materials from depositing on engine surfaces.

Metallo-organic detergents, on combustion, leave an ashy residue (see Section II.I, Sulfated Ash). In some cases, this may be detrimental in that the ash can contribute to

Copyright 2001 by Exxon Mobil Corporation. All Rights Reserved.

combustion chamber deposits. In other cases, it may be beneficial in that the ash provides wear-resistant coatings for surfaces such as valve faces and seats.

Typical dispersants (also called polymeric dispersants and ashless dispersants) in use today are described as polymeric succinimides, olefin/P_2S_5 reaction products, polyesters, and benzylamides. These are based on long chain hydrocarbons that are acidified and then neutralized with a compound containing basic nitrogen. The hydrocarbon portion provides oil solubility, while the nitrogen portion provides an active site that attracts and holds potential deposit-forming materials to keep them suspended in the oil.

While the primary use of detergents and dispersants is in engine oils, they are also being used in products such as automatic transmission fluids, hydraulic oils, and circulation oils for high temperature service. In these applications, the detergents and dispersants help to prevent the deposition of lacquer and varnish resulting from oil oxidation, thus supplementing the effects of the oxidation inhibitors.

G. Antiwear Additives

Antiwear additives are used in many lubricating oils to reduce friction, wear, and scuffing and scoring under boundary lubrication conditions, that is, when full lubricating films cannot be maintained. As the oil film becomes progressively thinner as a result of increasing loads or temperatures, contact through the oil film is first made by minute surface irregularities or asperities. As these opposing asperities make contact, friction increases and welding can occur. As sliding continues, the welds break immediately, but the process can form new roughness through metal transfer, as well as wear particles, which can cause scuffing and scoring. Two general classes of materials are used to prevent metallic contact, depending on the severity of the requirements.

Mild antiwear and friction-reducing additives, sometimes called boundary lubrication additives, are polar materials such as fatty oils, acids, and esters. They are long chain materials that form an adsorbed film on the metal surfaces with the polar ends of the molecules attached to the metal and the molecules projecting more or less normal to the surface. Contact is then between the projecting ends of the layers of molecules on the opposing surfaces. Friction is reduced, and the surfaces move more freely relative to each other. Wear is reduced under mild sliding conditions, but under severe sliding conditions the layers of molecules can be rubbed off, with the result that their wear-reducing effect is lost.

H. Extreme Pressure Additives

At high temperatures or under heavy loads where more severe sliding conditions exist, compounds called extreme pressure (EP) additives are required to reduce friction, control wear, and prevent severe surface damage. These materials function by chemically reacting with the sliding metal surfaces to form relatively oil insoluble surface films. The kinetics of the reaction are a function of the surface temperatures generated by the localized high temperatures that result from rubbing between opposing surface asperities, and breaking of junctions between these asperities.

Even with extreme pressure additives in the lubricant, wear of new surfaces may be high initially. In addition to the normal break-in wear, nascent metal (freshly formed, chemically reactive surfaces), time, and temperature are required to form the protective surface films. After the films have formed, relative motion is between the layers of surface films rather than the metals. The sliding process can lead to some film removal, but since

Copyright 2001 by Exxon Mobil Corporation. All Rights Reserved.

replacement by further chemical reaction is rapid, the loss of metal is extremely low. This process gradually depletes the amount of EP additive available in the oil, although the rate of depletion is usually very slow. Thus, there will be sufficient additive left to provide adequate protection for the metal surfaces except possibly under severe operating conditions, where makeup rates are low and normal drain intervals are exceeded.

The severity of the sliding conditions dictates the reactivity of the EP additives required for maximum effectiveness. The optimum reactivity occurs when the additives minimize the adhesive or metallic wear without leading to appreciable corrosive or chemical wear. Additives that are too reactive lead to the formation of excessively thick surface films, which have less resistance to attrition, so some metal is lost by the sliding action. Since a particular EP additive may have different reactivity with different metals, it is important to match additive metal reactivity to the additives not only with the severity of the sliding system but also with the specific metals involved. For example, some additives that are excellent for steel-on-steel systems may not be satisfactory for bronze-on-steel systems operating at similar sliding severity because they are too reactive with the bronze.

Another important function of EP additives is that because the chemical reaction is greatest on the asperities where contact is made and localized temperatures are highest, they lead to polishing of the surfaces. The load is then distributed more uniformly over a greater contact area, which allows for a reduction in sliding severity, more effective lubrication, and a reduction in wear.

Extreme pressure agents are usually compounds containing sulfur, chlorine, or phosphorus, either alone or in combination. The compounds used depend on the end use of the lubricant and the chemical activity required in it. Sulfur compounds, sometimes with chlorine or phosphorus compounds, are used in many metal-cutting fluids. Sulfur–phosphorus combinations are used in most industrial and automotive gear lubricants. These materials provide excellent protection against gear tooth scuffing and have the advantages of better oxidation stability, lower corrosivity, and often lower friction than other combinations that have been used in the past.

II. PHYSICAL AND CHEMICAL CHARACTERISTICS

A multitude of physical and chemical tests yield useful information on the characteristics of lubricating oils. However, the quality or the performance features of a lubricant cannot be adequately described on the basis of physical and chemical tests alone. Thus, major purchasers of lubricating oils, such as the military, equipment builders, and many commercial consumers, include performance tests as well as physical and chemical tests in their purchase specifications. Physical and chemical tests are of considerable value in maintaining uniformity of products during manufacture. Also, they may be applied to used oils to determine changes that have occurred in service, and to indicate possible causes for those changes.

Some of most commonly used tests for physical or chemical properties of lubricating oils are outlined in the following sections, with brief explanations of the significance of the tests from the standpoint of the refiner and consumer. For detailed information on methods of test, the reader is referred to the American Society for Testing and Materials handbooks (Annual Standards for Petroleum Products and Lubricants) the British Institute of Petroleum handbook (Standard Methods for Testing Petroleum and Its Products), the U.S. Federal Test Method Standard No. 791, and similar publications used in a number of other countries.

Copyright 2001 by Exxon Mobil Corporation. All Rights Reserved.

A. Carbon Residue

The carbon residue of a lubricating oil is the amount of deposit, in percentage by weight (wt %), left after evaporation and pyrolysis of the oil under prescribed conditions. In the test, oils from any given type of crude oil show lower values than those of similar viscosity containing residual stocks. Oils of naphthenic type usually show lower residues than those of similar viscosity made from paraffinic crudes. The more severe the refining treatment—whether an oil is subjected to solvents, hydroprocessing, filtration, or acid treatment—the lower the carbon residue value will be. Although many finished lubricating oils now contain additives that may contribute significantly to the amount of residue in the test, their effect on performance is distinctly beneficial.

Originally the carbon residue test was developed to determine the carbon-forming tendency of steam cylinder oils. In the years that followed, unsuccessful attempts were made to relate carbon residue values to the amount of carbon formed in the combustion chambers and on the pistons of internal combustion engines. Since such factors as fuel composition and engine operation and mechanical conditions, as well as other lubricating oil properties, are of equal or greater importance, carbon residue values alone have only limited significance. The carbon residue determination is now made mainly on base oils used for engine oil manufacture, straight mineral engine oils such as aircraft engine oils, and some products of the cylinder oil type used for reciprocating air compressors. In these cases, the determination is an indication of the degree of refining to which the base stock has been subjected.

B. Color

The color of lubricating oils as observed by light transmitted through them varies from practically clear or transparent to opaque or black. Usually, the various methods of measuring color are based on a visual comparison of the amount of light transmitted through a specified depth of oil with the amount of light transmitted through one of a series of colored glasses. The color is then given as a number corresponding to the number of the colored glass.

Color variations in lubricating oils result from differences in crude oils, viscosity, and method and degree of treatment during refining, and in the amount and nature of the additives included. During processing, color is a useful guide to the refiner to indicate whether processes are operating properly. In finished lubricants, color has little significance except in the case of medicinal and industrial white oils, which are often compounded into, or applied to, products in which staining or discoloration would be undesirable. Although color changes in used lube oils should not be taken as a condemning criterion, a color change accompanied by other physical changes such as odor or oxidation would possibly signal a need for action.

C. Density and Gravity

The density of a substance is the mass of a unit volume of it at a standard temperature. The specific gravity (relative density) is the ratio of the mass of a given volume of a material at a standard temperature to the mass of an equal volume of water at the same temperature. API gravity is a special function of specific gravity (sp gr), which is related

Copyright 2001 by Exxon Mobil Corporation. All Rights Reserved.

to it by the following equation:

$$\text{API gravity} = \frac{141.5}{\text{sp gr } 60/60^\circ\text{F}} - 131.5$$

The API gravity value, therefore, increases as the specific gravity decreases. Since both density and gravity change with temperature, determinations are made at a controlled temperature and then corrected to a standard temperature by use of special tables.

Density and gravity can be determined by means of hydrometers (Figure 3.4). The hydrometer can be calibrated to read any of the three properties: density, specific gravity, or API gravity.

Gravity determinations are quickly and easily made. Because products of a given crude oil, having definite boiling ranges and viscosities, will fall into definite ranges, this property is widely used for control in refinery operations. It is also useful for identifying oils, provided the distillation range or viscosity of the oils is known. The primary use of API gravity, however, is to convert weighed quantities to volume and measured volumes to weight.

In testing used oils, particularly used engine oils, a decrease in specific gravity (increase in API gravity) may indicate fuel dilution, whereas an increase in specific gravity might indicate the presence of contaminants such as fuel soot or oxidized materials. Additional test information is necessary to fully explain changes in gravity, since some effects tend to cancel others. For hydrocarbon-based materials, the API gravity can also be used

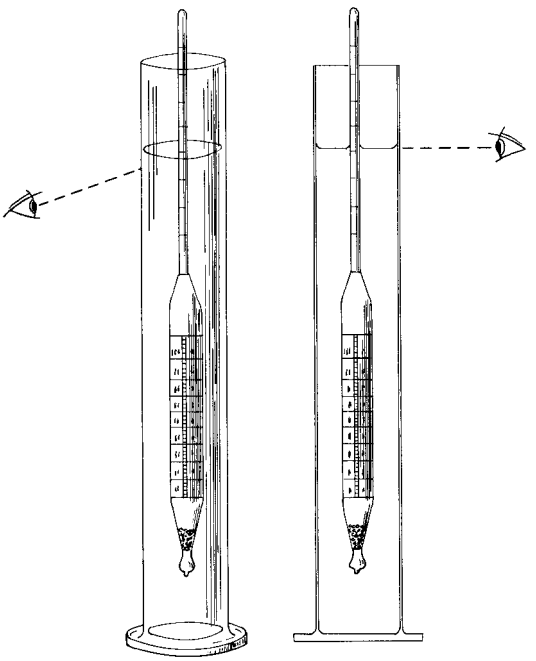

Figure 3.4 Use of hydrometer to determine density and gravity.

Copyright 2001 by Exxon Mobil Corporation. All Rights Reserved.

to determine the heating value of the material (Btu/gal). Tables are readily available to read these values directly once the API gravity has been determined.

D. Flash and Fire Points

The flash point of an oil is the temperature at which the oil releases enough vapor at its surface to ignite when an open flame is applied. For example, if a lubricating oil is heated in an open container, ignitable vapors are released in increasing quantities as the temperature rises. When the concentration of vapors at the surface becomes great enough, exposure to an open flame will result in a brief flash as the vapors ignite. When a test of this type is conducted under certain specified conditions, as in the Cleveland open cup method (Figure 3.5), the bulk oil temperature at which this happens is reported as the flash point. The release of vapors at this temperature is not sufficiently rapid to sustain combustion, so the flame immediately dies out. However, if heating is continued, a temperature will be reached at which vapors are released rapidly enough to support combustion. This temperature is called the fire point. For any specific product, flash and fire points will vary depending on the apparatus and the heating rate. Temperatures are raised in 5°F increments for this test.

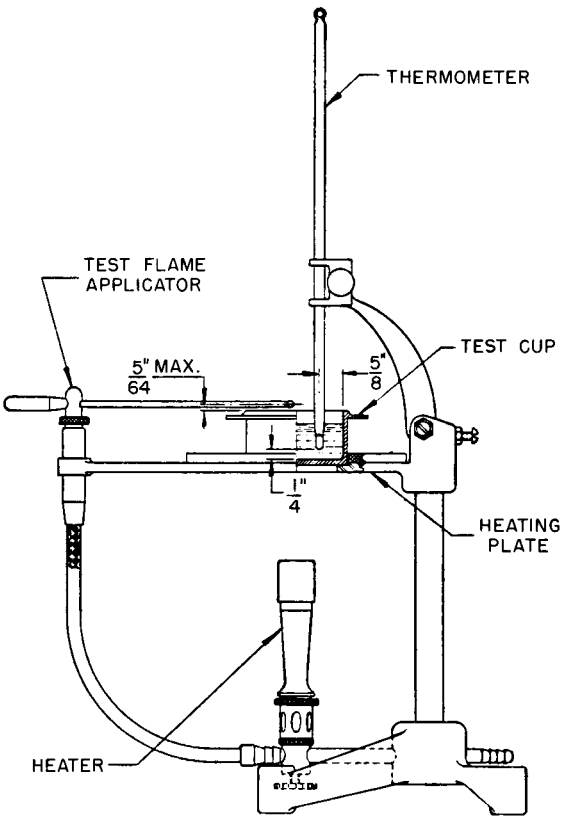

Figure 3.5 Cleveland open cup flash tester.

Copyright 2001 by Exxon Mobil Corporation. All Rights Reserved.

The flash point of new oils varies with viscosity: higher viscosity oils have higher flash points. Flash points are also affected by the type of crude and by the refining process. For example, naphthenic oils generally have lower flash points than paraffinic oils of similar viscosity.

Flash and fire tests are of value to refiners for control purposes and are significant to consumers under certain circumstances for safety considerations. Also, in certain high temperature applications, use of an oil with a low flash point, indicating higher volatility, may result in higher oil consumption rates. Flash and fire points are of little value in determining whether fire-resistant fluids are safe near possible points of ignition.

In the inspection of a used oil, a significant reduction in the flash point usually indicates contamination with lower flash material. An exception to this occurs when certain products are used for long periods at high temperatures and undergo thermal cracking with the formation of lighter hydrocarbons and a reduction in the original flash point.

E. Neutralization Number (NN)

Tests were developed to provide a quick determination of the amount of acid in an oil by neutralizing it with a base. The amount of acid in the oil was expressed in terms of the amount of a standard base required to neutralize a specified volume of oil. This quantity of base came to be called the neutralization number (NN) of the oil.

Some of the products of oxidation of petroleum hydrocarbons are organic acids. An oil oxidizes in service, caused by exposure to elevated temperatures, and there is a tendency for it to become more acidic. Thus, measuring the acidity of an oil in service was one way of following the progress of oxidation. This technique is still used with a number of products, primarily those intended for extended service, such as steam turbine oils and electrical insulating oils.

Many of the additives now used to improve performance properties may make an oil acidic or basic, depending on their composition. In other cases, the additives may contain weak acids and weak bases that do not react with each other in the oil solution, but do react with both the strong acid and the strong base used in the neutralization number tests to give both acidic and basic neutralization numbers. Other additives also undergo exchange reactions with the base used for neutralization to give false acid values in the test. These effects of the additives tend to obscure any changes in acidity occurring in the oil itself, so neutralization number determinations may have little significance for some oils containing additives.

F. Total Acid Number (TAN)

The total acid number (TAN) of an oil is synonymous with neutralization number. The TAN of an oil is the weight in milligrams of potassium hydroxide required to neutralize one gram of oil and is a measure of all the materials in an oil that will react with potassium hydroxide under specified test conditions. The usual major components of such materials are organic acids, soaps of heavy metals, intermediate and advanced oxidation products, organic nitrates, nitro compounds, and other compounds that may be present as additives. It is worth mentioning that new and used oil can exhibit both TAN and TBN (total base number) values.

Organic acids may form as a result of progressive oxidation of the oil, and the heavy metal soaps result from reaction of these acids with metals. Mineral acids (i.e., strong inorganic acids), if present in an oil sample, are neutralized by potassium hydroxide and

Copyright 2001 by Exxon Mobil Corporation. All Rights Reserved.

would, therefore, affect the TAN determination. However, such acids are seldom present except in internal combustion engines using high sulfur fuels or in cases of contamination.

Since a variety of degradation products contribute to the TAN value, and since the organic acids present vary widely in corrosive properties, the test cannot be used to predict corrosiveness of an oil under service conditions.

G. Total Base Number (TBN)

The total base number of an oil is the quantity of acid, expressed in terms of the equivalent number of milligrams of potassium hydroxide, that is required to neutralize all basic constituents present in one gram of oil. This test is normally used with oils that contain alkaline, acid-neutralizing, additives. The rate of consumption of these alkaline materials (TBN depletion) is an indication of the projected serviceable life of the oil. With used oils, it indicates how much acid-neutralizing additive remains in the oil. Typical oils of this nature include diesel engine oils for internal combustion engines that use fuels containing acid-producing constituents such as sulfur or chlorine. As long as any significant amount of TBN remains in the oil, there should not be any *strong acids* present. However, the nature of high alkaline and metallic antioxidant additives sometimes allow for both TAN and TBN values to be obtained on the same sample. This occurs for both new and used oils.

H. Pour Point

The pour point of a lubricating oil is the lowest temperature at which it will pour or flow when it is chilled without disturbance under prescribed conditions. Most mineral oils contain some dissolved wax and, as an oil is chilled, this wax begins to separate as crystal that interlock to form a rigid structure that traps the oil in small pockets in the structure. When this wax crystal structure becomes sufficiently complete, the oil will no longer flow under the conditions of the test. Since, however, mechanical agitation can break up the wax structure, it is possible to have an oil flow at temperatures considerably below its pour point. Cooling rates also affect wax crystallization; it is possible to cool an oil rapidly to a temperature below its pour point and still have it flow.

While the pour point of most oils is related to the crystallization of wax, certain oils, which are essentially wax free, have viscosity-limited pour points. In these oils the viscosity becomes progressively higher as the temperature is lowered until at some temperature no flow can be observed. The pour points of such oils cannot be lowered with pour point depressants, since these agents act by interfering with the growth and interlocking of the wax crystal structure.

Untreated lubricating oils show wide variations in pour points. Distillates from waxy paraffinic or mixed base crudes typically have pour points in the range of 80–120°F (27–49°C), while raw distillates from naphthenic crudes may have pour points on the order of 0°F (−18°C) or lower. After solvent dewaxing, the paraffin distillates will have pour points on the order of 20–0°F (−7 to −18°C); where lower pour points oils are required, pour point depressants are normally used.

From the consumer's viewpoint, the importance of the pour point of an oil is almost entirely dependent on its intended use. For example, the pour point of a winter-grade engine oil must be low enough to permit the oil to be dispensed readily and to flow to the pump suction in the engine at the lowest anticipated ambient temperatures. On the

Copyright 2001 by Exxon Mobil Corporation. All Rights Reserved.

other hand, there is no particular need for low pour points for oils to be used inside heated plants or in continuous service such as steam turbines, or for many other applications.

I. Sulfated Ash

The sulfated ash of a lubricating oil is the residue, in percent by weight, remaining after three processes: burning the oil, treating the initial residue with sulfuric acid, and burning the treated residue. It is a measure of the noncombustible constituents (usually metallic materials) contained in the oil.

New, straight mineral lubricating oils contain essentially no ash-forming materials. Many of the additives used in lubricating oils, such as detergents, contain metallo-organic components, which will form a residue in the sulfated ash test, and so the concentration of such materials in an oil is roughly indicated by the test. Thus, during manufacture, the test gives a simple method of checking to ensure that the additives have been incorporated in approximately the correct amounts. However, since the test combines all metallic elements into a single residue, additional testing may be necessary to determine if the various metallic elements are in the oil in the correct proportions.

Several manufacturers now include a maximum limit on sulfated ash content in their specifications for internal combustion engine oils of certain types. This is done in the belief that while the sulfated ash content results from the incorporation of materials intended to improve overall oil performance, excessive quantities of some of these materials may contribute to such problems as combustion chamber deposits, top ring wear, or port deposits in engines with two-stroke cycles.

With used oils, an increase in ash content usually indicates a buildup of contaminants such as dust and dirt, wear debris, wrong oil used as makeup, and possibly other contamination.

J. Viscosity

Probably the most important single property of a lubricating oil is its viscosity. A factor in the formation of lubricating films under both thick and thin film conditions, viscosity affects heat generation in bearings, cylinders, and gears; it governs the sealing effect of the oil and the rate of consumption or loss; and it determines the ease with which machines may be started under cold conditions. For any piece of equipment, the first essential for satisfactory results is to use an oil of proper viscosity to meet the operating conditions.

The basic concept of viscosity is shown in Figure 3.6, which shows a plate being drawn at a uniform speed over a film of oil. The oil adheres to both the moving surface and the stationary surface. Oil in contact with the moving surface travels with the same velocity U as that surface, while oil in contact with the stationary surface is at zero velocity. In between, the oil film may be visualized as being made up of many layers, each drawn by the layer above it at a fraction of velocity U that is proportional to its distance above the stationary plate (Figure 3.6, lower view). A force F must be applied to the moving plate to overcome the friction between the fluid layers. Since this friction is the result of viscosity, the force is proportional to viscosity. Viscosity can be determined by measuring the force required to overcome fluid friction in a film of known dimensions. Viscosity determined in this way is called *dynamic* or *absolute* viscosity.

Dynamic viscosities are usually reported in poise (P) or centipoise (cP; 1 cP = 0.01 P), or in SI units in pascal-seconds (Pa·s; 1 Pa·s = 10 P). Dynamic viscosity, which is a function only of the internal friction of a fluid, is the quantity used most frequently in

Copyright 2001 by Exxon Mobil Corporation. All Rights Reserved.

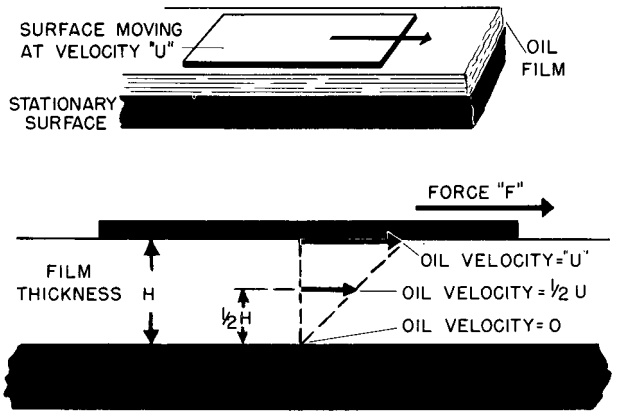

Figure 3.6 Concept of dynamic viscosity.

bearing design and oil flow calculations. Because it is more convenient to measure viscosity in a manner such that the measurement is affected by the density of the oil, *kinematic* viscosities normally are used to characterize lubricants.

The kinematic viscosity of a fluid is the quotient of its dynamic viscosity divided by its density, both measured at the same temperature and in consistent units. The most common units for reporting kinematic viscosities now are the stokes (St) or centistokes (cSt; 1 cSt = 0.01 St), or in SI units, square millimeters per second (mm^2/s; 1 mm^2/s = 1 cSt). Dynamic viscosities, in centipoise, can be converted to kinematic viscosities, in centistokes, by dividing by the density in grams per cubic centimeter (g/cm^3) at the same temperature. Kinematic viscosities, in centistokes, can be converted to dynamic viscosities, in centipoise, by multiplying by the density in grams per cubic centimeter. Kinematic viscosities, in square millimeters per second (mm^2/s), can be converted to dynamic viscosities, in pascal-seconds, by multiplying by the density, in grams per cubic centimeter, and dividing the result by 1000.

Other viscosity systems, including those of Saybolt, Redwood, and Engler, are in use and will probably continue to serve for many years because of their familiarity to some people. However, the instruments developed to measure viscosities in these systems are rarely used. Most actual viscosity determinations are made in centistokes and converted to values in the other systems by means of published SI conversion tables.

The viscosity of any fluid changes with temperature—increasing as the temperature is decreased, and decreasing as the temperature is increased. Thus, it is necessary to have some method of determining the viscosities of lubricating oils at temperatures other than those at which they are measured. This is usually accomplished by measuring the viscosity at two temperatures, then plotting these points on special viscosity–temperature charts developed by ASTM. A straight line can then be drawn through the points and viscosities at other temperatures read from it with reasonable accuracy, as illustrated in Figure 3.7. The line should not be extended below the pour point or above approximately 300°F (for most lubricating oils) since in these regions it may no longer be straight.

The two temperatures most used for reporting viscosities are 40°C (104°F) and 100°C (212°F).

Copyright 2001 by Exxon Mobil Corporation. All Rights Reserved.

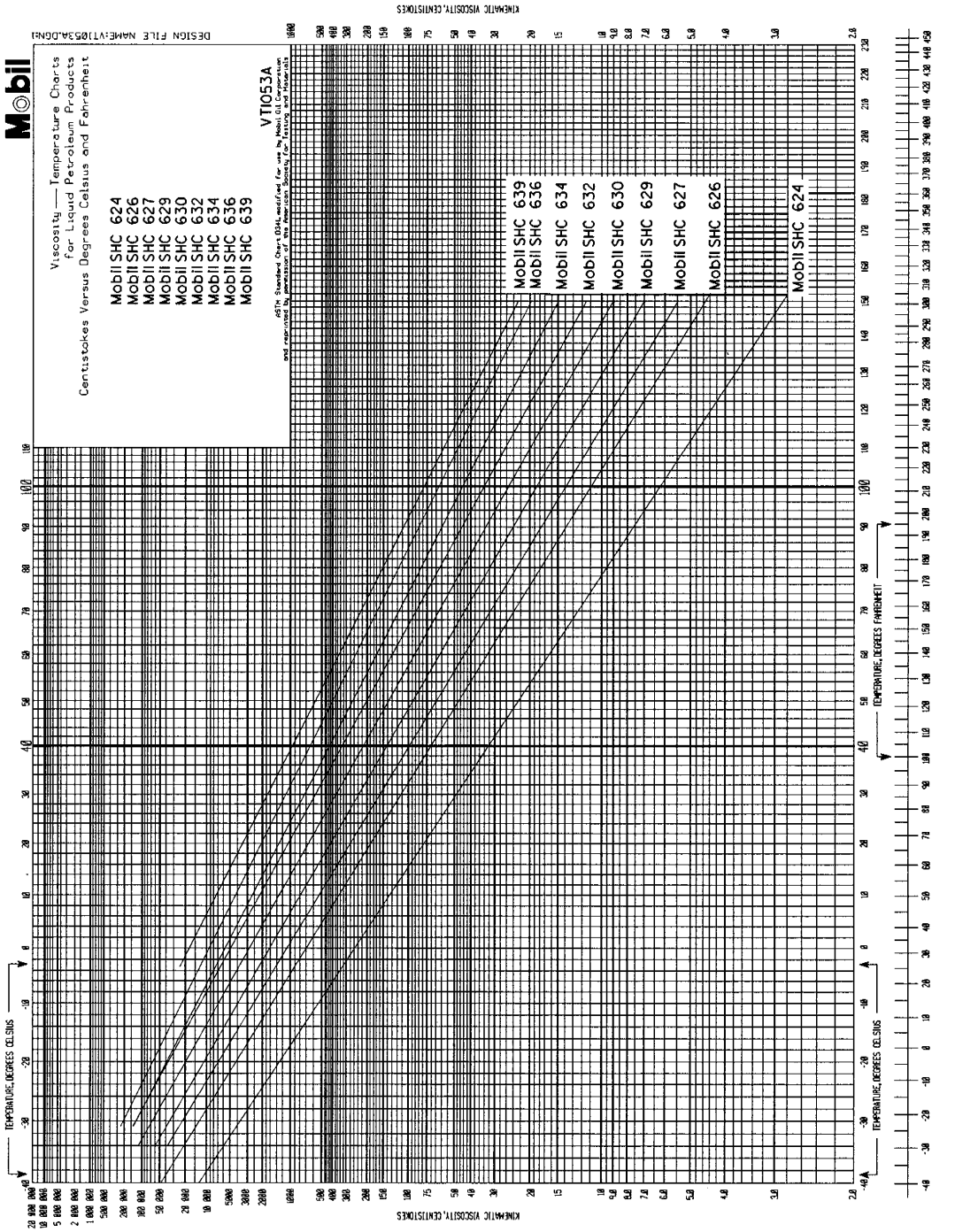

Figure 3.7 ASTM viscosity–temperature chart.

Copyright 2001 by Exxon Mobil Corporation. All Rights Reserved.

In selecting the proper oil for a given application, viscosity is a primary consideration. It must be high enough to provide proper lubricating films but not so high that friction losses in the oil will be excessive. Since viscosity varies with temperature, it is necessary to consider the actual operating temperature of the oil in the machine. Other considerations, such as whether a machine must be started at low ambient temperatures, must also be taken into account.

Three viscosity numbering systems are in use to identify oils according to viscosity ranges. Two of these are for automotive lubricants and one for industrial oils.

1. Engine Oil Viscosity Classification

SAE (Society of Automotive Engineers) Standard J300 classifies oils for use in automotive engines by viscosities determined at low shear rates and high temperature (100°C), at high shear rate and high temperature (150°C), and at both low and high shear rates at low temperature (-5°C to -40°C). The ranges for grades in this classification are shown in Table 3.1.

In these classifications, grades with the suffix letter W are intended primarily for use at low ambient temperatures, while grades without the suffix letter are intended for

Table 3.1 Engine Oil Viscosity Classification: SAE J300 (April 1997)[a]

SAE viscosity grade	Low temperature (°C) cranking viscosity (cP, max)[b]	Low temperature (°C) pumping viscosity (cP, max, with no yield stress)[c]	Kinematic viscosity (cSt) at 100°C min[d]	Kinematic viscosity (cSt) at 100°C max[d]	High shear viscosity (cP), at 150°C and 10^6 s^{-2}, min[e]
0W	3250 at -30	60 000 at -40	3.8	—	—
5W	3500 at -25	60 000 at -35	3.8	—	—
10W	3500 at -20	60 000 at -30	4.1	—	—
15W	3500 at -25	60 000 at -25	5.6	—	—
20W	4500 at -20	60 000 at -20	5.6	—	—
25W	6000 at -5	60 000 at -15	9.3	—	—
20	—	—	5.6	$<$ 9.3	2.6
30	—	—	9.3	$<$ 12.5	2.9
40	—	—	12.5	$<$ 16.3	2.9[f]
40	—	—	12.5	$<$ 16.3	3.7[g]
50	—	—	16.3	$<$ 21.9	3.7
60	—	—	21.9	$<$ 26.1	3.7

[a] All values are critical specifications as defined by ASTM D 3244.
[b] ASTM D 5293.
[c] ASTM D 4684. Note that the presence of any yield stress detectable by this method constitutes a failure regardless of viscosity.
[d] ASTM 445.
[e] ASTM D 4683 or ASTM D 4741.
[f] 0W-40, 5W-40, and 10W-40 grades.
[g] 15W-40, 20W-40, 25W-40 and 40 grades.

Copyright 2001 by Exxon Mobil Corporation. All Rights Reserved.

use where low ambient temperatures will not be encountered. Multigrade oils are used for year-round service in automotive engines except for some 2 two-stroke diesel engines. An example of a multigrade oil is as follows: oils can be formulated that will meet the low temperature limits of the 5W grade and the 100°C limits for the 30 grade. Such a product can then be designated an SAE 5W-30 grade and is referred to as a multigrade or multiviscosity oil. Oils of this type generally require the use of VI improvers (see Section I: Additives) in conjunction with petroleum or synthetic lubricating oil base stocks.

High Temperature–High Shear (HT/HS) viscosities are measured at 150°C by ASTM Standard D 4683 or D 4741. The HT/HS is measured under shear stresses similar to those experienced in engine bearings. The HT/HS value indicates the temporary shear stability of the viscosity index (VI) improvers used to formulate multigrade engine oils. The SAE J300 classification shows that a SAE 40 grade oil must have a HT/HS rate viscosity exceeding 3.69 cP at 150°C or it will not perform as a 40 grade oil under engine operating conditions.

At low temperature, the high shear rate viscosity is measured by ASTM D 5293, a multitemperature cold cranking simulator method. The low temperature, low shear rate viscosity is measured by ASTM D 4684. Results of both tests have been shown to correlate with engine starting and engine oil pumpability at low temperatures.

This SAE system is widely used by engine manufacturers to determine suitable oil viscosities for their engines, and by oil marketers to indicate the viscosities of internal combustion engine oils.

2. Axle and Manual Transmission Lubricant Viscosity Classification

SAE Recommended Practice J306 classifies lubricants for use in automotive manual transmissions and drive axles by viscosity measured at 100°C (212°F), and by maximum temperature at which they reach a viscosity of 150,000 cP (150 Pa·s) when cooled and measured in accordance with ASTM Standard D 2983 (Method of Test for Apparent Viscosity at Low Temperature Using the Brookfield Viscometer).

The limits for lubricant oil viscosity are given in Table 3.2. Multigrade oils such as 80W-90 or 85W-140 can be formulated under this system. This limiting viscosity of 150,000 cP was selected on the basis of test data indicating that lubrication failures of pinion bearings of a specific axle design could be experienced when the lubricant viscosity exceeded this value. Since other axle designs, as well as transmissions, may have higher

Table 3.2 Axle and Manual Transmission Lubricant Viscosity Classification-SAE J306*

SAE viscosity grade	Maximum temperature for viscosity of 150,000 cP (°C)	(cSt) Viscosity at 100° Celsius	
		Minimum	Maximum
70W	−55	4.1	—
75W	−40	4.1	—
80W	−26	7.0	—
85W	−12	11.0	—
90	—	13.5	24.0
140	—	24.0	41.0
250	—	41.0	—

Copyright 2001 by Exxon Mobil Corporation. All Rights Reserved.

Table 3.3 Viscosity System for Industrial Fluid Lubricants

Viscosity system grade identification	Midpoint viscosity [cSt (mm^2/s)] at 40.0°C	Kinematic viscosity limits [cSt (mm^2/s)] at 40.0°C	
		Minimum	Maximum
ISO VG 2	2.2	1.98	2.42
ISO VG 3	3.2	2.88	3.52
ISO VG 5	4.6	4.14	5.06
ISO VG 7	6.8	6.12	7.48
ISO VG 10	10	9.00	11.0
ISO VG 15	15	13.5	16.5
ISO VG 22	22	19.8	24.2
ISO VG 32	32	28.8	35.2
ISO VG 46	46	41.4	50.6
ISO VG 68	68	61.2	74.8
ISO VG 100	100	90.0	110
ISO VG 150	150	135	165
ISO VG 220	220	198	242
ISO VG 320	320	288	352
ISO VG 460	460	414	506
ISO VG 680	680	612	748
ISO VG 1000	1000	900	1100
ISO VG 1500	1500	1350	1650

or lower limiting viscosities, it is the responsibility of the gear manufacturer to specify the actual grades that will provide satisfactory service under different ambient conditions.

3. Viscosity System for Industrial Fluid Lubricants

A system was developed jointly by ASTM and the Society of Tribologists and Lubrication Engineers (STLE) to establish a series of definite viscosity levels that could be used as a common basis for specifying or selecting the viscosity of industrial fluid lubricants, and to eliminate unjustified intermediate grades. The system was originally based on viscosities measured at 100°F but was converted to viscosities measured at 40°C in the interests of international standardization. In this form, the system now appears as ASTM Standard D 2422, American National Standard Z11.232, (British Standards Institution Standard BS 4231, Deutsches Institut für Normung) (DIN) No. 51519, and International Standards Organization (ISO) Standard 3448. The ISO viscosity ranges and identifying grade numbers are shown in Table 3.3. Figure 3.8 is an easy conversion chart to other viscosity classification systems.

K. Viscosity Index

Different oils have different rates of change of viscosity with temperature. For example, a distillate oil from a naphthenic base crude would show a greater rate of change of viscosity with temperature than would a distillate oil from a paraffin crude. The viscosity index is a method of applying a numerical value to this rate of change, based on comparison

Copyright 2001 by Exxon Mobil Corporation. All Rights Reserved.

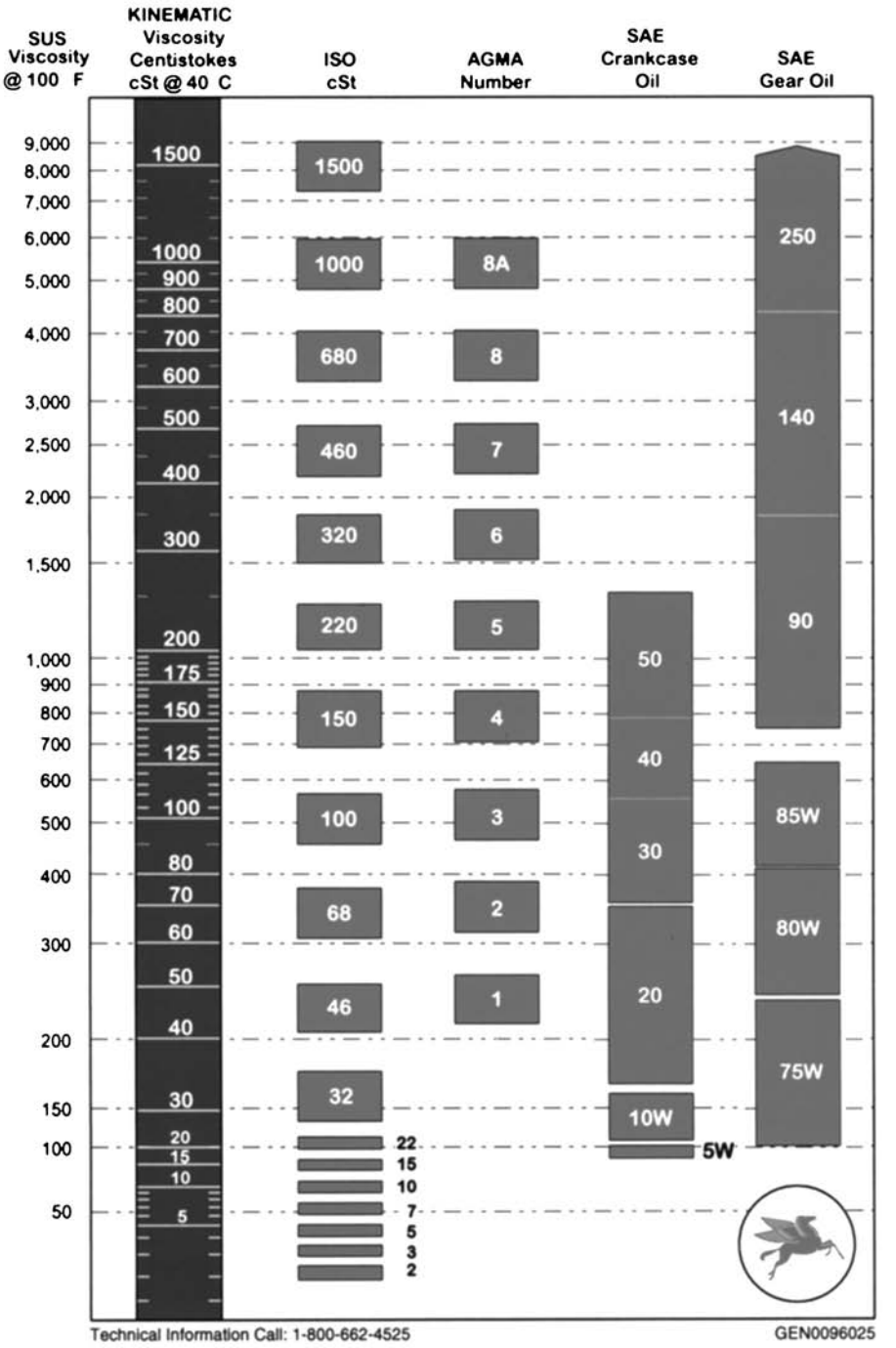

Figure 3.8 Viscosity equivalents.

Copyright 2001 by Exxon Mobil Corporation. All Rights Reserved.

with the relative rates of change of two arbitrarily selected types of oil that differ widely in this characteristic. A high VI indicates a relatively low rate of change of viscosity with temperature; a low VI indicates a relatively high rate of change of viscosity with temperature. For example, consider a high VI oil and a low VI oil having the same viscosity at, say, room temperature: as the temperature increased, the high VI oil would thin out less and, therefore, would have a higher viscosity than the low VI oil at higher temperatures.

The VI of an oil is calculated from viscosities determined at two temperatures by means of tables published by ASTM. Tables based on viscosities determined at both 100°F and 212°F, and 40°C and 100°C are available.

Finished mineral-based lubricating oils made by conventional methods range in VI from somewhat below 0 to slightly above 100. Mineral oil base stocks refined through special hydroprocessing techniques can have VIs well above 100. Some synthetic lubricating oils have VIs both below and above this range. Additives called VI improvers can be blended into oils to increase VIs; however, VI improvers are not always stable in lubricating environments exposed to shear or thermal stressing. Accordingly, these additives must be used with due care to assure adequate viscosity over the anticipated service interval for the application for which they are intended.

In many types of service, where the operating temperature remains more or less constant, VI is of little concern. However, in services where the operating temperature may vary over a wide range, such as in passenger car engines, it is probably safe to say that the VI of the oil used should be as high as practicable, consistent with other performance properties.

III. EVALUATION AND PERFORMANCE TESTS

Testing under actual service conditions is the best way to evaluate the performance of a lubricant and should be the final evaluation used before a new product or new formulation is placed on the market. Service testing is not always practical, however, during the early phases of lubricant development because of the time and cost involved. Therefore, shorter and less costly tests are used in the laboratory during development of both commercial and experimental lubricants. The correlation of results from these laboratory bench and rig tests with field performance has been a major effort of petroleum laboratories for many years. Many tests have been proposed, but a large proportion of them have been discarded for various reasons. Most of the tests that have survived have done so because they have shown the ability to predict with a fair degree of reliability some of the aspects of how a lubricant will perform in service.

Selecting lubricants based solely on meeting a set of laboratory bench tests will not always guarantee meeting the requirements of an application. Most standard laboratory test procedures were developed for evaluating *new* oil under laboratory conditions with some expectations of correlation to field application. In a lab test that is completed in minutes to months, it is extremely difficult to duplicate operating conditions and contamination for equipment that operates over a period of years. This is why extensive field testing of new products must be an integral part of new product development.

Since the process of test development and refinement is continuing, the following discussion treats the tests in a fairly general manner.

A. Oxidation Tests

Oxidation of lubricating oils depends on the temperature, amount of oxygen contacting the oil, and the catalytic effects of metals. If the oil's service conditions are known, these

Copyright 2001 by Exxon Mobil Corporation. All Rights Reserved.

three variables can be adjusted to provide a test that closely represents actual service. However, oxidation in service is often an extremely slow process, so the test may be time-consuming. To shorten the test time, the test temperature is usually raised and catalysts added to accelerate the oxidation. Unfortunately, these measures tend to make the test a less reliable indication of expected field performance. As a result, very few oxidation tests have received wide acceptance, although a considerable number are used by specific laboratories that have developed satisfactory correlations for them.

One oxidation test that is widely used is ASTM D 943, Oxidation Characteristics of Inhibited Steam-Turbine Oils. This test is commonly known as TOST (turbine oil stability test). While TOST is intended mainly for use on inhibited steam turbine oils, it has been used for hydraulic and circulation oils, and for base oils for use in the manufacture of turbine, hydraulic, and circulation oils. The test is operated at a moderate temperature (95°C, 203°F). Iron and copper catalyst wires are immersed in the oil sample, to which water is added. Oxygen is bubbled through the sample at a prescribed rate. The test is run either for a prescribed number of hours, after which the neutralization number of the oil is determined, or until the neutralization number reaches a value of 2.0. The result in the latter case is than reported as the hours to a neutralization number of 2.0.

Objections to ASTM D 943 are that extremely long test times, often on the order of several thousand hours, are required for stable oils, and that the only criterion for acceptability is the neutralization number. Severe sludging and deposits on the catalyst wires can occur with some oils without excessive increase in the neutralization number. A modification of the procedure, called procedure B, overcomes some of these latter objections by requiring a determination of the sludge content.

Two additional oxidation tests that are used primarily in Europe are the IP 280 procedure for turbine oils and the PNEUROP procedure of the Comité Européen des Constructeurs de Compresseurs et d'Outillage for compressor oils. Because of ISO activities in international standardization, these tests are also receiving attention in the United States.

In the IP 280 procedure, often referred to as the CIGRE test (for **C**onférence **I**nternationale des **G**randes **R**eseaux **E**lectriques à Haute Tension), oxygen is passed through a sample of oil containing soluble iron and copper catalysts. The sample is held at 120°C (248°F) and test time is 164 h. During the test, volatile acids formed are absorbed in an absorption tube. At the end of the test, the acid numbers of the oil and the absorbent are determined and combined to give the total acidity; the sludge is determined as a weight percent. These may then be further combined to give the total oxidation products. Compared to ASTM D 943, the CIGRE test requires a short, fixed test time, and the amount of sludge formed during the test is an important criterion of the evaluation. Where the limits for satisfactory performance in the test are properly set, some believe that good correlation with performance in modern turbines is obtained. A concern of the procedure is the use of an oil soluble catalyst which does not recognize the benefits of oils that specifically resist catalyst dissolution in service.

In the PNEUROP test, a sample of oil containing iron oxide as a catalyst is aged by being held at 200°C (392°F) for 24 h while air is bubbled through it. At the end of the test, the evaporation loss and the Conradson carbon residue (CCR) of the remaining sample are determined. The evaporation loss is significant only in that it must not exceed 20%, so the main criterion is the CCR value. The test is believed to correlate to some extent with the tendency of oils to form carbonaceous deposits on compressor valves.

Copyright 2001 by Exxon Mobil Corporation. All Rights Reserved.

B. Thermal Stability

Thermal stability, as opposed to oxidation stability, is the ability of an oil or additive to resist decomposition under prolonged exposure to high temperatures with minimal oxygen present. Decomposition may result in thickening or thinning of the oil, increasing acidity, the formation of sludge, or any combination of these.

Thermal stability tests usually involve static heating, or circulation over hot metal surfaces. Exposure to air is usually minimized, but catalyst coupons of various metals may be immersed in the oil sample. While no tests have received wide acceptance, a number of proprietary tests are used to evaluate the thermal stability of products such as hydraulic fluids, gas engine oils, and oils for large diesel engines.

C. Rust Protection Tests

The rust-protective properties of lubricating oils are difficult to evaluate. Rusting of ferrous metals is a chemical reaction that is initiated almost immediately when a specimen is exposed to air and moisture. Once initiated, the reaction is difficult to stop. Thus, when specimens are prepared for rust tests, extreme care must be taken to minimize exposure to air and moisture so that rusting will not start before the rust-protective agent has been applied and the test begun. Even with proper precautions, rust tests do not generally show good repeatability or reproducibility.

Most laboratory rust tests involve polishing or sandblasting a test specimen, coating it with the oil to be tested, then subjecting it to rusting conditions. Testing may be in a humidity cabinet, by atmospheric exposure, or by some form of dynamic test. In the latter category is ASTM D 665, Rust Preventive Characteristics of Steam Turbine Oil in the Presence of Water. In this test, a steel specimen is immersed in a mixture of distilled or synthetic seawater and the oil under test. The oil and water moisture is stirred continuously during the test, which usually lasts for 24 h. The specimen is then examined for rusting.

The IP 220 ''Emcor'' method is used widely in Europe for oils and greases. This procedure employs actual ball bearings, which are visually rated for rust on the outer races at the end of the test. This is a dynamic test that can be run with a given amount of water flowing into the test bearing housings. Severity may be increased with the use of salt water or acid water in place of the standard distilled water.

Other dynamic tests may involve testing of actual mechanisms lubricated with test oil, as in the CRC L-33 test described in Automotive Gear Lubricant Tests. Additional rust tests for automotive engines are discussed later on in this chapter (Section IV, Engine Tests for Oil Performance).

D. Foam Tests

The most widely used foam test is ASTM D 892, Foaming Characteristics of Lubricating Oils. Air is blown through an oil sample held at a specified temperature for a specified period of time. Immediately after blowing is stopped, the amount of foam is measured and reported as the foaming tendency. After a specified period of time to allow for the foam to collapse, the volume of foam is again measured and reported as the foam stability.

This test gives a fairly good indication of the foaming characteristics of new, uncontaminated oils, but service results may not correlate well if contaminants such as moisture or finely divided rust, which can aggravate foaming problems, are present in a system. For a number of applications, such as automatic transmission fluids, special foam tests

Copyright 2001 by Exxon Mobil Corporation. All Rights Reserved.

involving severe agitation of the oil have been developed. These are generally proprietary tests used for specification purposes.

E. EP and Antiwear Tests

One of the main functions of a lubricant is to reduce mechanical wear. Closely related to wear reduction is the ability of lubricants of the extreme pressure (EP) type to prevent scuffing, scoring, and seizure as applied loads are increased. As a result, a considerable number of machines and procedures have been developed to try to evaluate EP and antiwear properties. In a number of cases, the same machines are used for both purposes, although different operating conditions may be used.

Wear can be divided into four classifications based on the cause:

Abrasive wear
Corrosive (chemical) wear
Adhesive wear
Fatigue wear

1. Abrasive Wear

Abrasive wear is caused by abrasive particles, either contaminants carried in from outside or wear particles formed as a result of adhesive wear. In either case, oil properties do not have much direct influence on the amount of abrasive wear that occurs, except through their ability to carry particles to filtering systems that remove them from the circulating oils.

2. Corrosive or Chemical Wear

Corrosive or chemical wear results from chemical action on the metal surfaces combined with rubbing action that removes corroded metal. A typical example is the wear that may occur on cylinder walls and piston rings of diesel engines burning high sulfur fuels. The strong acids formed by combustion of the sulfur can attack the metal surfaces, forming compounds that can be fairly readily removed as the rings rub against the cylinder walls. Direct measurement of this wear requires many hours of test unit operation, which is often done as the final stage of testing new formulations. However, useful indications have been obtained in relatively short periods of time by means of sophisticated electronic techniques. Rusting is a chemical action that may result from long periods of inoperation, high moisture conditions, and inability of the oil to protect nonwetted surfaces. On equipment start-up, the rust is removed in contact areas, not only resulting in loss of surface metal but also generating particles that cause abrasive wear.

3. Adhesive Wear

Adhesive wear in lubricated systems occurs when, owing to load, speed, or temperature conditions, the lubricating film becomes so thin that opposing surface asperities can make contact. If adequate extreme pressure additives are not present, scuffing and scoring can result, and eventually seizure may occur. Adhesive wear can also occur with extreme pressure lubricants when the reaction kinetics of the additives with the surfaces are such that metal-to-metal contact is not fully controlled.

A number of machines, such as the Almen, Alpha LFW-1, Falex, Four-Ball, SAE, Timken, and Optimol SRV, are used to determine the loading conditions under which

Copyright 2001 by Exxon Mobil Corporation. All Rights Reserved.

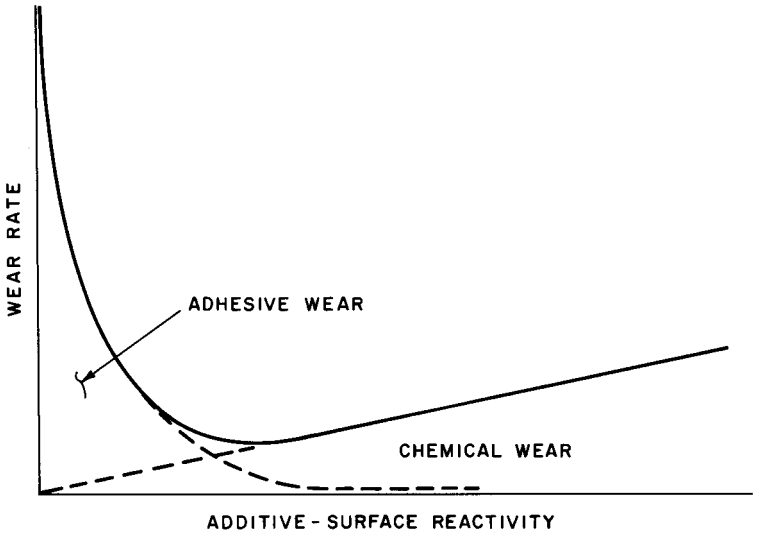

Figure 3.9 Balance of adhesive and chemical wear.

seizure, welding, or drastic surface damage to test specimens would be permitted. Of these, the Alpha LFW-1, Four-Ball, Falex, Timken, and Optimol SRV are also used to measure wear at loads below the failure load. The results obtained with these machines do not necessarily correlate with field performance, but in some cases, the results from certain machines have been reported to provide useful information for specific applications. As shown in Figure 3.9 as additive reactivity increases, adhesive wear decreases and chemical wear increases. To some extent, the machines used to judge additive surface reactivity also can be used in selecting additives for optimum effectiveness in balancing adhesive and chemical wear for certain metal combinations.

Either actual machines or scale model machines are used in testing the antiwear properties of lubricants. Antiwear-type hydraulic fluids are tested for antiwear properties in pump test rigs using commercial hydraulic pumps of the piston-and-vane type. Frequently, industrial gear lubricants are tested in the FZG Spur Gear Tester, a scale model machine that reasonably approximates commercial practice with respect to gear tooth loading and sliding speeds. Correlation of the FZG test with field performance has been good.

4. Fatigue Wear

Fatigue wear occurs under certain conditions when the lubricating oil film is intact and metallic contact of opposing asperities is either nil or relatively small. Cyclic stressing of the surfaces causes fatigue cracks to form in the metal, leading to fatigue spalling or pitting. Fatigue wear occurs in rolling element bearings and gears when there is a high degree of rolling, and adhesive wear, associated with sliding, is negligible. A variation of the fatigue pitting wear is the micropitting wear mechanism that results in small pits in the surfaces of some gears and bearings. Asperity interaction and high loads as well as metallurgy are factors influencing micropitting. An upgraded version of the standard FZG Spur Gear Tester is used to evaluate gear oil micropitting performance according to a German Research Institute test method called FVA (Forschungsvereinigung Antriebstechnik) Method 54.

Copyright 2001 by Exxon Mobil Corporation. All Rights Reserved.

The understanding of the influence of lubricant composition and characteristics is an evolving technology. Some products are currently available that address fatigue-induced wear in antifriction bearings and gears caused by the presence of small amounts of water in the hertzian load zones. In these instances, the fatigue is called *water-induced fatigue,* and oil chemistry can reduce the negative effects of water in the load zones of antifriction bearings and gears. Two tests have been introduced by Institute of Petroleum for studies of this type. In IP 300/75, Pitting Failure Tests for Oils in a Modified Four-Ball Machine, oils are tested under conditions that cause cyclic stressing of steel bearing balls. To shorten the test time, the load and stress are set higher than is usual for the ball bearings. In another British test, IP 305/74, The Assessment of Lubricants by Measurement of Their Effect on the Rolling Fatigue Resistance of Bearing Steel Using the Unisteel Machine, a ball thrust bearing with a flat thrust ring is used. The flat thrust ring is the test specimen. With a flat thrust ring, stresses are higher than would be normally encountered if a raceway providing better conformity were machined in the ring. Both tests are run in replicate. Results to date indicate that both tests provide useful information on the effect of lubricant physical properties and chemical composition on fatigue life under cyclic stressing conditions. Pitting of gears can be assessed by using the standard FZG Spur Gear Test and the method developed by FVA.

F. Emulsion and Demulsibility Tests

In some cases, lubricating oils are expected to mix with water to form emulsions. Products such as marine steam engine oils, rock drill oils, soluble cutting oils, and certain types of metal rolling lubricant are examples of products that should form stable emulsions with water. Moisture is usually present in the lubricated areas served by marine steam engine oils and rock drill oils, and emulsification with this water is necessary to form adherent lubricating films that protect the metal surfaces against wear and corrosion. Soluble cutting oils and some types of rolling oil are designed to be mixed with water to provide the high cooling capability of water combined with some lubricating properties.

Various proprietary tests for emulsion stability are in use. In addition, the recommendations of ASTM D 1479 Emulsion Stability of Soluble Cutting Oils, and ASTM D 3342, Emulsion Stability of New (Unused) Rolling Oil Dispersion in Water, are used to some extent. Both tests require agitation of the oil sample with water under prescribed conditions. In ASTM D 1479, the emulsion is then allowed to settle for 24 h, a bottom portion of it is broken with acid and centrifuged, and the oil content is compared with the oil content of a freshly prepared emulsion. The difference is reported as the oil depletion of the stored sample. In ASTM D 3324, bottom samples are withdrawn periodically, broken with acid, centrifuged, and analyzed to determine the oil content. A logarithmic plot of the oil content versus time is then prepared to determine an average rate of separation of the emulsion.

Lubricating oils used in circulating systems should separate readily from water that may enter the system as a result of condensation, leakage, or splash of process water. If the water separates easily, it will settle to the bottom of the reservoir, where it can be periodically drawn off. Steam turbine oils, hydraulic fluids, and industrial gear oils are examples of products for which it is particularly important to have good water separation properties. These properties are usually described as the emulsion, demulsibility, or demulsification characteristics.

To determine the emulsion and demulsibility characteristics of lubricating oils, three tests are widely used: ASTM D 1401, ASTM D 2711, and IP 19.

Copyright 2001 by Exxon Mobil Corporation. All Rights Reserved.

ASTM D 1401, Emulsion Characteristics of Petroleum Oils and Synthetic Fluids, was developed specifically for steam turbine oils with viscosities of 150–450 SUS at 100°F (32–97 cSt at 38°C), but can be used for testing lower and higher viscosity oils and synthetic fluids. The normal test temperature is 130°F (54°C), but for oils more viscous than 450 SUS at 100°F, it is recommended that the test temperature be increased to 180°F (82°C). In the test, equal parts of oil (or fluid) and water are stirred together for 5 min. The time for separation of the emulsion is recorded. If complete separation does not occur after the mixture has been allowed to stand for an hour, volumes of oil (or fluid), water, and emulsion remaining are reported.

ASTM D 2711, Demulsibility Characteristics of Lubricating Oils, is intended for use in testing medium and high viscosity oils such as paper machine oil applications that are prone to water contamination and may encounter the turbulence of pumping and circulation capable of producing water-in-oil emulsions. A modification of the test is suitable for evaluation of oils containing extreme pressure additives. In the test, water and the oil under test are stirred together for 5 min at 180°F (82°C). After the mixture has been allowed to settle for 5 h, the percentage of water in the oil and the percentages of water and emulsion separated for the oil are measured and recorded.

IP 19, Demulsification Number, is intended for testing new inhibited and straight mineral turbine oils. A sample of the oil held at about 90°C is emulsified with dry steam. The emulsion is then held in a bath at 94°C and the time in seconds for the oil to separate is recorded and reported as the demulsification number. If the complete separation has not occurred in 20 min, the demulsification number is reported as 1200+.

Properly used, these three tests have value in describing the emulsion or demulsibility characteristics of new lubricating oils. The IP 19 procedure is sometimes used in describing products that emulsify readily, as well as products that easily separate from water. A demulsification number of 1200+ is sometimes specified for such products as rock drill oils where the formation of lubricating emulsions is desired.

IV. ENGINE TESTS FOR OIL PERFORMANCE

A large number of engine tests are currently used to qualify oils for specific categories of classification. This number continues to expand as new or additional engine and oil characteristics are needed to meet not only the requirements of the engines but also to satisfy environmental regulations. Most of the standardized tests are designed to evaluate oils intended for automotive type engines: that is, relatively small, high speed diesel engines and four-stroke-cycle gasoline engines. Considerable effort has been devoted to standardizing the tests in the United States, Europe, and Asia. The effects of this standardization can be seen in the API licenses granted in a recent 12-month period. During this period, approximately 50% of the API licenses were granted to companies outside the United States, making the API classification system for automotive engine oils an international system. The API went from an Engine Service Classification System (ESCS) to an Engine Oil Licensing and Classification System (EOLCS) in 1994.

The ASTM establishes test procedures and limits and has published the Multicylinder Engine Test Sequences for Evaluation of Automotive Engine Oils (Sequences IID, IIIE, VE, and VIB) in Special Technical Publication STP 315, and the Single Cylinder Engine Tests for Evaluating Crankcase Oils (L-38, 1-G2, 1-H, 1-N, 1-K and 1-P) in STP 509. In addition, the major diesel engine manufacturers have developed engine tests that are part of the API classification system. These tests were initially developed for qualifying oils

Copyright 2001 by Exxon Mobil Corporation. All Rights Reserved.

Table 3.4 Gasoline and Diesel Engine Oil Tests

Engine test	Principle parameter(s) evaluated
L-38	Bearing corrosion
Sequence IID	Rust and corrosion
Sequence IIIE	Oxidation, varnish, cam wear
Sequence VE	Sludge, cam wear
KA24E	Cam wear
Sequence VIB	Fuel economy
Mack T-6	Oil consumption, oxidation, piston cleanliness
Mack T-7	Oil thickening
Mack T-8 (T-8E)	Oxidation, soot, filterability
Mack T-9	Ring-liner wear, bearing wear, extended drain capability
Cat 1-K	Piston cleanliness, oil consumption, ring and liner scuffing
Cat 1M-PC	Piston cleanliness, varnish, ring and liner wear
Cat 1-N	Piston cleanliness, ring and liner wear, oil consumption
Cat 1-P	Deposit control, oil consumption
DD 6V-92TA	Wrist pin bushing wear, liner scuffing, port deposits
Cummins M-11	Bearing corrosion, sliding wear, filterability, sludge
GM 6.2, 6.5 liter	Roller cam follower wear, ring sticking

for their specific engines. Examples are the Mack EO-L, EO-L Plus, and EO-M using the Mack T-6, T-8, and T-9 engine tests. Cummins Diesel uses the NTC 400 and the M-11 tests. All these engine tests are very expensive to develop and run, significantly increasing the cost of engine oil development and testing. All these tests can be grouped into eight categories of performance measurement:

1. Tests for oxidation stability and bearing corrosion protection
2. Single-cylinder high temperature tests
3. Multicylinder high temperature tests
4. Multicylinder low temperature tests
5. Rust and corrosion protection
6. Oil consumption rates and volatility
7. Emissions and protection of emission control systems
8. Fuel economy

A summary of the common engine oil tests used in the U.S. is shown in Table 3.4. Some additional new engine tests or extensions of existing engine tests are used to evaluate the ability of oils to provide extended drain capability. The ability to extend drain intervals is important to builders because of the pressure from users to reduce costs associated with maintenance and also to conserve nonrenewable resources. Extended drain capability is perceived by users to mean higher quality engines and oils.

A. Oxidation Stability and Bearing Corrosion Protection

Several engine tests are used to evaluate the ability of an oil to resist oxidation and oil thickening under high temperature conditions as well as to protect sensitive bearing materi-

Copyright 2001 by Exxon Mobil Corporation. All Rights Reserved.

als from corrosion. The tests are operated under conditions that promote oil oxidation and the formation of oxyacids that cause bearing corrosion. Copper-lead inserts are used for connecting rod and main bearings in many gasoline and diesel engines. Even the few engines that use aluminum rod and main bearings will use a lead-tin flashing for break-in purposes. Although the aluminum bearings are more resistant to oxyacid corrosion, they can still experience some effects of acids in the oil. After the tests have been completed, the bearing inserts are examined for surface condition and weight loss to determine the protection afforded by the oil. The engine is also rated for varnish and sludge deposits. The most commonly used bearing corrosion test is the CRC L-38 (CEC L-02-A-78), but the Mack T-9 engine test also evaluates bearing protection capabilities of the oil.

B. Single-Cylinder High Temperature Tests

Single-cylinder engines are designed and operated to duplicate longer term operating conditions in a laboratory. They are specifically designed for oil test purposes. The tests are used primarily for the evaluation of detergency and dispersancy: that is, the ability of the oil to control piston deposits and ring sticking under operating conditions or with fuels that tend to promote the formation of piston deposits. These tests also evaluate oil consumption rates. All the current single-cylinder tests are of the diesel engine design. After completion of the test, the engine is disassembled and rated for piston deposits, top ring groove filling, and wear. The operating conditions for several of these tests are shown in Table 3.5.

C. Multicylinder High Temperature Engine Tests

While the single-cylinder engine tests just discussed provide useful information and are extremely valuable in the development of improved oil formulations, there is a trend toward use of full-scale commercial engines for oil testing and development. This trend has been precipitated by the different needs of the various engine designs as well by the requirement to satisfy demands for reduced emissions and improved fuel economy. The full-scale engine tests are used to evaluate several of the oil's performance characteristics under the different conditions subjected by the various designs. Oxidation stability, deposit control, wear and scuffing, and valve train wear are a few of the oil characteristics evaluated

Table 3.5 Single-Cylinder Engine Oil Test Conditions

Test	1-K	1-N	1-P	MWM-B	Petter AV-B
Area of use	U.S.A.	U.S.A.	U.S.A.	Europe	Europe
Fuel injection	DI	DI	DI	IDI	IDI
Aspiration	SC	SC	SC	NA	SC
Displacement	2.4 liters	2.4 liters	2.2 liters	0.85 liters	0.55 liters
Load	52 kW	52 kW	55 kW	10.5 kW	11 kW
Rpm	2100	2100	1800	2200	2250
Oil capacity	6.0 liters	6.0 liters	6.8 liters	3.2 liters	3.0 liters
Test duration	252 h	252 h	360 h	50 h	50 h
Oil temperature	107°C	107°C	130°C	110°C	90°C

Copyright 2001 by Exxon Mobil Corporation. All Rights Reserved.

Table 3.6 Multicylinder Test Conditions

Test	Sequence IIIE	Sequence VE	Sequence VIA	Mack T-8
Engine	Buick V-6	Ford OHC-4	Ford V-8	Mack E.7
Fuel	Gasoline	Gasoline	Gasoline	Diesel
Displacement	3.8 liters	2.3 liters	4.6 liters	12.0 liters
Oil capacity	5.3 liters	3.67 liters	5.7 liters	45.4 liters
Test duration	64 h	288 h	50 h	250 h
Rpm	3000	I 2500 II 2500 III 750	800–1500	1800
Load	50.6 kW	25/25/0.75	kW 2.18–15.39 kW	258 kW
Oil temperature C	149°C	68/99/46°C	45–105°C	100–107°C

by these tests. Some of the full-scale engine tests used to evaluate the oil's performance characteristics are the ASTM sequence IIIE, Mack T-6 and T-7, the XUD 11ATE (CEC L-56-T-95), the OM 602A (CEC L-51-T-95), and the Toyota 1G-FE (JASO M 333-93). Several of the multicylinder test conditions are shown in Table 3.6.

D. Multicylinder Low Temperature Tests

Since many engines can idle for long periods of time, particularly in diesel engines in colder weather or in driving conditions characterized by frequent starting and stopping, it is important that the oil have enough detergency and dispersancy to satisfactorily control soot (unburnt fuel) and sludge in engines. Both sludges and soot will increase an oil's viscosity in addition to reducing antiwear protection, filterability, and fuel economy (higher viscosity reduces fuel economy). The oil's detergency and dispersancy characteristics must be balanced with the other performance requirements to handle the negative effects of soot and reduce the buildup of sludge in the engines that can often occur in low temperature operations. Several multicylinder tests are designed to predict the oil's ability to handle the soot and sludging. The Mack T-8, the M111 (CEC L-53-T-95), and the Sequence VE tests are used to evaluate low temperature sludge and soot handling capabilities of oils.

E. Rust and Corrosion Protection Tests

The ability to protect metal parts from rust and corrosion has received more attention in the United States than in many other countries, probably because of the high proportion of stop-and-go driving in combination with severe winter weather. These conditions tend to promote condensation and accumulation of partially burnt fuel in the crankcase oil, both of which promote rust and corrosion in addition to the soot and sludge problems already discussed. Two engine tests are currently used to evaluate rust and corrosion protection properties of oils. These are the Mack T-9 and the sequence IID. At the end of the tests, valve train components, oil pump relief valves, and bearings are rated for rust and any sticking of lifters and relief valves is noted. The Sequence IID test will be gradually replaced by the *ball rust test* (BRT).

Copyright 2001 by Exxon Mobil Corporation. All Rights Reserved.

F. Oil Consumption Rates and Volatility

There is a direct association with an oil's volatility characteristics and oil consumption rates. Although volatility is not the sole reason for oil consumption in any given engine, it provides a measure of the oil's ability to resist vaporization at high temperatures. Typically, distillations were run to determine volatility characteristics of base stocks used to formulate engine oils. This is still true today. The objective of further defining an oil's volatility led to the introduction of several new *nonengine* bench tests. The most common of these tests is the NOACK Volatility, Simulated Distillation, or ''sim-dis'' (ASTM D 2887), and the GCD Volatility (ASTM D 5480). All these tests measure the amount of oil in percent that is lost upon exposure to high temperatures and therefore, serve as a measure of the oil's relative potential for increased or decreased oil consumption during severe service. Reduced volatility limits are placing more restraints on base stock processing and selection and the additive levels to achieve the required volatility levels. As discussed in Chapter 2 (Refining Processes and Lubricant Base Stocks), more and more of the base stocks used to formulate engine oils will be from API groups II, III and IV, group IV being PAOs. In addition to the bench tests already discussed, many of the actual engine tests monitor and report oil consumption rates as part of the test criteria. Caterpillar, Cummins, and Mack are all concerned about controlling oil consumption for extended service conditions.

G. Emissions and Protection of Emission Control Systems

Control of engine emissions is becoming increasingly important because of health aspects as well as the long-term effects in the earth's atmosphere (greenhouse effects). As a result, pressure is being placed on engine builders and users to reduce engine emissions. These emissions include sulfur dioxide, oxides of nitrogen, carbon monoxide, hydrocarbons, and particulates. An oil can contribute to an engine's emissions in several ways. The most common is by providing a seal between the pressure in the combustion chamber at the rings and pistons. Wear or deposits in this area will reduce combustion efficiency and lead to greater emissions. Control of piston land and groove deposits is crucial to maintaining low oil consumption rates and long-term engine performance. Oil can also contribute to increased emissions by blocking or poisoning catalysts on the engines equipped with catalytic converters. Blocking of catalyst reactions can occur through excessive oil consumption, and the poisoning effects result from chemical components either in the fuel or the oil's additive package. A common additive used in engine oil formulations is phosphorus, an element known to poison catalysts; yet phosphorus is a key element for protecting the long-term performance of engines. Since phosphorus cannot currently be effectively eliminated from engine oil formulations, the oils are formulated to keep oil consumption rates low, which minimizes the effects of phosphorus that gets into the exhaust gases.

H. Fuel Economy

Related to emissions, the trend is to increase the fuel efficiency of both gasoline and diesel engines. The first engine test developed to measure fuel economy was the Sequence VI, which was developed in the mid-1980s with a Buick V-6. This test was well correlated to the now obsolete ASTM five-car test method. The Sequence VIA replaced the Sequence VI in the mid-1990s, substituting a 1993 Ford 4.6-liter V-8. A new test, the Sequence VIB, is replacing Sequence VIA in 2001. All the fuel economy tests indicate the importance of oil viscosity in achieving mandated CAFE (corporate average fuel economy) requirements. The lower viscosity oils such as the 10W-30s and 5W-30s, and now 0W-20s which

Copyright 2001 by Exxon Mobil Corporation. All Rights Reserved.

are the principal recommendations of the automobile manufacturers, provide measurable economy benefits relative to heavier viscosity grades. Although the foregoing tests are used to measure an oil's contribution to fuel economy, the official federal test uses a carbon balance of the tailpipe emissions, and it is this test that is used to establish compliance to CAFE requirements.

V. AUTOMOTIVE GEAR LUBRICANTS

The automotive vehicles manufactured today and in the past have all required gearing of some sort to allow transfer of the engine's power to the driving wheels. This gearing is composed of a range of gear design encompassing spur, helical, herringbone, and/or hypoid gears. All these gears require lubrication. Just as there is a wide range of gearing and application requirements, so is there a range of performance levels to meet mild to severe operating and application conditions.

Finished gear lubricants typically are composed of high quality base stocks (mineral and/or synthetics) and between 5 and 20% additive, depending on desired performance characteristics. Up to as many as 10 different additive materials could be used to formulate these oils and, based on the increasing requirements of extended service intervals and environmental concerns, more may be needed. These additives include antiwear compounds, extreme pressure agents, oxidation stabilizers, metal deactivators, foam suppressors, corrosion inhibitors, pour point depressants, dispersants, and viscosity index improvers. As with the other high performance lubricants, these additives compete with each other to perform their functions and must be balanced to provide the required performance requirements.

Three primary technical societies composed of and working in conjunction with equipment builders, lubricant formulators, additive suppliers, and the users of the equipment have combined efforts to define automotive gear lubricant requirements. These three technical societies are SAE, ASTM, and API. SAE has established the viscosity classification system (SAE J306) for automotive gear lubricants shown earlier (Table 3.2). ASTM establishes test methods and criteria for judging performance levels and defining test limits. API defines performance category language. In addition to SAE, ASTM, and API, the U.S. military has established a widely used specification for automotive gear lubricants: MIL-PRF-2105E.

Unlike automotive engine oils, there are no current licensing requirements for gear oils by API. Some major OEMs, however, offer licenses to use their designations for transmission and axle lubricants.

The API performance categories are as follows:

API GL-1 Lubricants for manual transmissions operating under mild service conditions. These oils do not contain antiwear, extreme pressure, or friction modifier additives. They do contain corrosion inhibitors, oxidation inhibitors, pour point depressants, and antifoam agents.

API GL-4 Lubricants for differentials containing spiral bevel or hypoid gearing operating under moderate to severe conditions. These oils may be used in some manual transmissions and transaxles where EP oils are acceptable.

API GL-5 Lubricants for differentials containing hypoid gears operating under severe conditions of torque and occasional shock loading. These oils generally contain high levels of antiwear and extreme pressure additives.

Copyright 2001 by Exxon Mobil Corporation. All Rights Reserved.

Table 3.7 Gear Lubricant Testing

Characteristic	API GL-5	API MT-1
Corrosion resistance	CRC L-33	ASTM D130
Load-carrying capability	CRC L-37	ASTM D5182
Scoring resistance	CRC L-42	ASTM D5182
Oxidation stability	CRC L-60	ASTM D5704
Elastomer compatibility	—	ASTM D5662
Cyclic durability	—	ASTM D5579
Foam resistance	ASST. D892	ASTM D892
Gear oil compatibility	FTM 3430/3440	FTM 3430/3440

API MT-1 Lubricants for manual transmissions that do not contain synchronizers. These oils are formulated to provide higher levels of oxidation and thermal stability when compared to API GL-1, GL-4 and GL-5 products.

The military specification MIL-PRF-2105E combines the performance levels of both the API GL-5 and MT-1 (Table 3.7).

In addition to the automotive gear lubricant tests, various car and other automotive axle and transmission manufacturers have gear tests, many of which are conducted in cars or over-the-road vehicles, either on dynamometers or in actual road tests. These tests generally represent special requirements such as the ability of lubricants to provide satisfactory performance in limited slip axles. Generally, most laboratory and bench testing has shown good correlation to field performance.

VI. AUTOMATIC TRANSMISSION FLUIDS

Automatic transmission fluids are among the most complex lubricants now available. In the converter section, these fluids are the power transmission and heat transfer medium; the gearbox, they lubricate the gears and bearings and control the frictional characteristics of the clutches and bands; and in control circuits, the act as hydraulic fluids. All these functions must be performed satisfactorily over temperatures ranging from the lowest expected ambient temperatures to operating temperatures on the order of 300°F (149°C) or higher, and for extended periods of service. Obviously, very careful evaluation is required before a fluid can be considered acceptable for such service.

The major U.S. automotive companies (General Motors, Ford, and DaimlerChrysler) continue to strive for improved automatic transmission fluids (ATF's). These improvements are aimed at fill-for-life applications (100,000–150,000 miles), which means that improvements are needed in oxidation stability, antiwear retention, shear stability, low temperature fluidity, material compatibility, and fluid friction stability. Ford Motor Company is looking at additional improvements to their Mercon V; GM will update Dexron III to Dexron IV; and DaimlerChrysler has improved its MS 7176D specification to MS 9602.

BIBLIOGRAPHY

Mobil Technical Bulletins

Engine Oils Specifications and Tests—Significance and Limitations
Additives for Petroleum Oils
Extreme Pressure Lubricant Test Machines

Copyright 2001 by Exxon Mobil Corporation. All Rights Reserved.